

## MUSHROOM STEM WAFER PEDESTAL FOR IMPROVED CONDUCTANCE AND UNIFORMITY

### INTRODUCTION

1. The present invention relates generally to the field of manufacturing semiconductor devices. More particularly, the present invention relates to equipment and processes for supporting a semiconductor wafer inside a processing chamber.

### BACKGROUND OF THE INVENTION

2. When manufacturing semiconductor devices, uniformity and consistency are imperatives. The various manufacturing steps (etching, deposition, etc.) are carried out under vacuum conditions in the controlled environment provided by specially designed chambers.

3. The shape and size of a processing chamber affects how the low pressure gasses behave inside it, and thus, affects how the semiconductor work piece is treated by those gasses. Of particular concern is the problem of how to maintain uniformity of pressure across the surface of the work piece. Even the slightest differential of pressure at one point on the work piece relative to another point can make a substantial difference in how consistently the surface of the work piece is transformed by the molecules that come in contact with it. Present day process chamber configurations are afflicted with processing inconsistency due to just such pressure differentials.

4. Referring to **Fig. 1**, a structure for supporting a semiconductor wafer in a processing chamber according to the prior art is illustrated. A semiconductor wafer **30** is inserted into a processing chamber **10** where it rests on a cylindrical support structure **20**. The cylindrical support structure **20** takes up the better part of the interior volume of the processing chamber **10**. Gases inside the vacuum chamber **10** are evacuated through the space between the cylindrical support structure **20** and the inner wall of the chamber **10**. The gas then exits the processing chamber **10** via a pumping port that is offset to one side to a vacuum pump (a turbomolecular pump TMP is shown).

5. This type of processing chamber configuration exhibits a detrimental pressure gradient across the wafer surface. The pressure gradient is produced by the fact that gas

molecules in the space just above the cylindrical support structure **20** have very different minimum path lengths to the vacuum chamber, depending upon their starting position above the wafer **30**. The longer the minimum path length to the vacuum pump, the greater the pressure at that location above the wafer.

6. Referring to **Fig. 2**, a processing chamber and cylindrical support according to another prior art configuration is illustrated. Inside the processing chamber **40**, a semiconductor wafer **70** to be processed is supported on a cylindrical support **50**, which is supported by cantilever supports **60** that extend from the walls of the chamber **40**. Although the entrance **80** to the vacuum pump is centered below the wafer **70** and its cylindrical support structure **50**, the minimum path length for gas molecules across the surface of the wafer **70** is still not very uniform. Gas molecules near the side of the wafer where the cantilever support **60** is present have a substantially longer minimum path length to the entrance **80** of the vacuum pump (i.e., dodging around the cantilever supports **60**) than do the molecules at other points across the wafer **70**. Again, this contributes to anisotropic pressure condition across the surface of the wafer **70**.

7. Another disadvantage of this configuration is that it does not permit z-axis (i.e., along a vertical axis) movement of the cylindrical support structure **50**.

8. Referring to **Fig. 3**, a cross sectional view of a processing chamber **12** according to still another prior art configuration is illustrated. The chamber **12** has two processing regions **18** for processing two wafers at the same time. The two processing regions **18** are evacuated via a plurality of exhaust ports **31** that are in communication with a circumferential pumping channel **25** formed in the chamber walls.

9. Referring to **Fig. 4**, a plan view of the processing chamber of Fig. 3 is illustrated. The exhaust path is shown in this view. The circumferential pumping channels **25** of each processing region **18** are connected to a common vacuum pump via a common exhaust channel **19**. The exhaust channel **19** is connected to the pumping channels **25** of each processing region **18** by exhaust conduits **21**. The exhaust channel **19** is connected to a vacuum pump via an exhaust line (not shown).

10. Referring to **Fig. 5**, a cross sectional view of a processing chamber according to yet another prior art configuration is illustrated. The chamber **39** has a processing region

**42** for processing a wafer. The processing region **42** is evacuated via a circumferential pumping channel **53** formed in the chamber walls. An exhaust channel **57**, connected to the pumping channel **53** of the processing region **42**, provides an exhaust connection to a vacuum pump via an exhaust line (not shown).

11. The configurations of Figs. 3 to 5 share the same problem as those of Figs. 1 and 2 in that pressure gradients are induced across the surface of the wafer being processed because of the pronounced asymmetry of minimum path length for molecules at the wafer surface. Offset pump configurations (Figs. 1 and 3 to 5) and the cantilevered support configurations (Fig. 2) inherently have this problem. The pressure gradient contributes substantially to non-homogeneous processing across the surface of the wafer.

12. Thus, what is needed is a chamber design that provides a reduced pressure differential across the wafer surface by providing a more uniform minimum path length from the surface of the wafer to the pumping port.

13. Another challenge for semiconductor processing is how to provide consistent conditions in two processing chambers at the same time so that two semiconductor work pieces may be processed simultaneously. Semiconductor processing technology presently available does not provide consistent conditions between two nominally identical chambers because each of the chambers has its own independent vacuum pump. Subtle differences between how the two vacuum pumps perform are amplified by the gas conduction paths to cause substantial variations in the pressure profile (both spatially and temporally) in the two chambers despite the fact that the control commands for the chambers' operating parameters are the same. This problem is a barrier to increasing production by performing the same processing step on multiple wafers simultaneously.

14. Thus, what is also needed is a way to maintain consistent pressure profile conditions simultaneously in two process chambers.

### **SUMMARY OF THE INVENTION**

15. One aspect of the present invention is to provide enhanced uniformity of process conditions for a semiconductor wafer being processed inside a processing chamber.

16. It is another aspect of the present invention that more uniform pressure conditions are provided for a semiconductor work piece being processed inside a vacuum chamber.

17. Another aspect of the present invention is a twin wafer processing chamber that provides for increased throughput of wafers being processed by providing for substantially identical processing conditions for a pair of wafers simultaneously.

18. It is yet another aspect of the present invention that semiconductor wafer processing chambers are provided having a reduced physical footprint than has been possible in the prior art.

19. It is a still further aspect of the present invention to provide for substantial identical conditions for plural semiconductor wafers in a processing chamber via design shape, gas conductance, and gas delivery parameters, without resort to active controls to maintain the identical conditions.

20. It is another aspect of the present invention to provide a wafer support structure that has a support stem, supporting the chuck from below, which is substantially narrower than the chuck.

21. It is yet another aspect of the present invention to provide a wafer support structure having a chuck with its services being provided via a supporting stem that is substantially narrower than the width of the chuck.

22. It is another aspect of the present invention to provide a chuck and supporting stem structure that promotes pressure uniformity inside a wafer processing chamber.

23. It is a further aspect of the present invention that a wafer supporting structure provides for increased chamber volume beneath the chuck so that the volume above the chuck may be reduced while maintaining the same overall chamber volume.

24. One embodiment of the present invention is a processing chamber that has a wafer support structure having a generally mushroom shape. A broad round chuck for supporting a wafer to be processed is supported from beneath by a stem. The services for the chuck are all provided via the stem. The pumping port for evacuating the chamber is placed substantially beneath the chuck.

25. The chamber for processing a semiconductor article has a chamber body, a chuck, and a stem. The chamber body has a bottom wall wherein the pumping port is formed. The chuck is located inside the chamber body and has an upper surface and a lower

surface that faces the bottom wall. The width of the chuck is sufficient to support the semiconductor article on the upper surface. The stem supports the chuck and extends from the bottom wall of the chamber body to the lower surface of the chuck. The width of the stem is substantially smaller than the width of the chuck.

26. Others of the above aspects of the present invention are embodied by a chamber for simultaneously processing two semiconductor articles (i.e., wafers) under substantially identical process conditions. The chamber includes chamber body with a pumping port disposed in its bottom wall, and a vacuum pump in fluid communication with the pumping port. A pair of article supports, as well as respective stems supporting those article supports, is disposed in the chamber. Each article support has an upper surface and a lower surface that faces the bottom wall of the chamber body. The stems support their respective article support by extending from the bottom wall of the chamber body to the lower surface of the article support. The article supports are each sufficiently wide to support a semiconductor article on their upper surface. The width of each stem is substantially smaller than the width of its article support.

27. Still others of the above aspects are embodied by a wafer support assembly for use in supporting a semiconductor wafer in a processing chamber. The wafer support assembly includes a wafer support (i.e., a chuck) and a stem. The wafer support has an upper side that is sufficiently wide to support the semiconductor wafer. The stem extends from a lower side of the wafer support and is substantially smaller in width than the wafer support.

28. Additional objects and advantages of the present invention will be apparent in the following detailed description read in conjunction with the accompanying drawing figures.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

29. Fig. 1 illustrates a partial section view of a process chamber with a cylindrical wafer support structure according to a first prior art configuration.

30. Fig. 2 illustrates a partial section view of a process chamber with a cantilevered wafer support structure according to a second prior art configuration.

31. Fig. 3 illustrates a cross sectional view of a processing chamber according to still a third prior art configuration.

32. Fig. 4 illustrates a plan view of the processing chamber of Fig. 3.
33. Fig. 5 illustrates a cross sectional view of a processing chamber according to yet a fourth prior art configuration.
34. Fig. 6 illustrates a partial section view of a process chamber having a configuration according to a first embodiment of the present invention.
35. Fig. 7 illustrates a partial section view of a process chamber having a configuration according to a second embodiment of the present invention.
36. Fig. 8 illustrates a partial section view of a dual processing region wafer processing system according to a third embodiment of the present invention.
37. Fig. 9 illustrates a partial section view of another dual processing region wafer processing system according to a fourth embodiment of the present invention.
38. Fig. 10 illustrates a partial section view of a wafer support structure consistent with the various embodiments of the present invention.

#### **DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION**

39. A chamber configuration according to the present invention produces at least two salient advantages.
40. One useful advantage of the novel combination of wafer supporting structure and pump out geometries according to this invention is reduction of the pressure gradient across the surface of wafers being processed in the chamber. This reduction in the pressure gradient is advantageous because it promotes uniformity of processing across the surface of the wafer, thereby increasing the number of highest quality chips produced per wafer.
41. Another useful advantage of the present invention is the high fluid conductance of the chamber. A wafer supporting structure as disclosed here increases chamber volume beneath the chuck so that the volume above the chuck may be reduced (as the chuck is moved upward in the chamber) while maintaining the same overall chamber volume. This large volume below the chuck happens to be the portion of the chamber through which gas flows to reach the pumping port at the bottom wall of the chamber, and because its volume is larger its conductance as a fluid flow path is larger. With a higher conductance pump

out path, the pump can do a better job of maintaining stable pressure at the surface of the wafer.

42. Additionally, larger interior chamber fluid volume adds to process stability because transients in pressure or flow are easier to manage in a larger volume. Maintaining such a large interior fluid volume without increasing the exterior size of the chamber yields an increased degree of process stability without increasing the footprint (i.e., how much real estate the chamber takes up on a production floor) of the chamber.

43. Referring to **Fig. 6**, a wafer supporting chuck according to an embodiment of the present invention is illustrated. A wafer **350** is inserted into the chamber **330** through a wafer transfer passage **334**. After being inserted into the chamber **330**, the wafer **350** rests upon the chuck **310**. The chuck **310** is supported inside the chamber **330** by a relatively thin stem **320**. The stem **320** extends from the bottom surface **312** of the chuck **310** to the bottom wall **332** of the chamber **330**. Services are provided to the chuck **310** from outside the chamber via a portion of the stem **314** that extends beyond the bottom wall **332** of the chamber **330**. Preferably, the services provided via the external stem portion **314** include RF energy, DC potential for an electrostatic chucking function, helium gas, and coolant.

44. Another aspect of the stem **320** is that it has bellows **322**. The bellows **322** permits the length of the stem **320** to be adjusted from a lowered position to a raised position and back again. In the lowered position, the chuck **310** is positioned so as to permit the wafer **350** to be easily transferred in and out of the chamber **330** via the wafer transfer passage **334**. When the wafer **350** is to be processed, the chuck **310** is elevated to the raised position by increasing the length of the stem **320**. Raising the chuck **310** places the wafer **350** closer to the shower head **336**, located at the top of the chamber **330**, that provides reagent gas. This up-and-down, z-axis motion is provided so that during processing the plasma cloud is cannot "see" the wafer transfer passage **334**, thus preventing the plasma cloud from being distorted by extending into the wafer transfer passage **334**.

45. Vacuum conditions inside the chamber **330** are maintained by a vacuum pump **340** coupled to the pumping port **324** in the bottom wall **332** of the chamber **330**. Importantly, the pumping port **324** is located at least partially beneath the chuck **310**. This placement has the effect of substantially equalizing the minimum path lengths for molecules traveling from the space above the wafer **350** to the pumping port **324**.

46. Referring to **Fig. 7**, a wafer support structure according to another embodiment of the present invention is illustrated. A chuck **410** supports a wafer **450** to be processed inside the chamber. The chuck **410** is, in turn, supported by a relatively thin stem **420**, extending from the bottom side **412** of the chuck **410** to the bottom wall **432** of the chamber **430**. According to this embodiment, the stem **420** is offset from the center of the chuck **410**. This offset configuration makes it possible to place the pumping port, disposed in the bottom wall **432**, to be either directly centered or almost centered beneath the chuck **410**. This provides an even more enhanced affect of equalizing the minimum path length for gas molecules above the wafer **450** to travel to the pumping port **424**, which is evacuated by the vacuum pump **440**.

47. Bellows **422** is provided on the stem **420** to permit the length of the stem **420** to be changed, thus raising and lowering the chuck **410**. When the chuck **410** is in a lowered position, the wafer **450** may be inserted into or removed from the chamber **430** via the wafer transfer passage **434**. When the wafer **450** is to be processed, the chuck **410** is raised into its raised position, thus placing the wafer **450** into proximity of the showerhead **436**, which distributes reagent gases into the space above the wafer **450**. This up-and-down, z-axis motion is provided so that during processing the plasma cloud is cannot "see" the wafer transfer passage **434**, thus preventing the plasma cloud from being distorted by extending into the wafer transfer passage **434**.

48. Services are provided to the chuck **410** via a portion **414** of the stem **420** that extends beyond the bottom wall **432** of the chamber **430**.

49. Referring to **Fig. 8**, a dual processing region alternate embodiment according to the present invention is illustrated. Twin processing regions **530**, **580** are disposed adjacent to one another in a single chamber **500** to provide substantially identical processing conditions for a pair of wafers **550**, **590**. The two processing regions **530**, **580** are separated from one another by a partition **502** that extends down at least below the chucks **510**, **560**.

50. Each of the processing regions **530**, **580** has a respective chuck **510**, **560** on which the respective wafers **550**, **590** are supported for processing. The illustration of the wafers **550**, **590** and their supporting chucks **510**, **560** in phantom indicates a raised position for

the chucks that places the wafers **550**, **590** in close proximity to the gas distribution shower heads **536**, **586**.

51. In a lowered position, the chuck **512** is disposed just below the level of the wafer transfer passage **534** through which the wafer **550** passes into and out of the processing region **530**. Likewise, the chuck **562** in the adjacent processing region **580** is disposed just below the level of the wafer transfer passage **588** when in its lowered position.

52. The chuck **512** in the left-hand processing region **530** is supported via a stem **526** having an inner portion **528** that is free to move upwardly thus placing the chuck **510** in its upper position. Likewise the chuck **562** of the right-hand processing region **580** is supported by a stem **576** having an inner portion **578** that is free to move upwardly thus placing the chuck **560** in an upward position. The change of length aspect of the stems **526**, **576** is preferably facilitated by respective bellows structures (not shown in this view) that are interior to the illustrated stem portions **526**, **528**, **576**, **578**.

53. According to this embodiment, the stems **526**, **576** are offset from the center of their respective chucks **512**, **562**. This offset configuration maximizes the proportion of the chucks that hang over the pumping port **524**.

54. The two processing regions **530**, **580** are pumped to vacuum via a common vacuum pump **540**. Gases in the left-hand processing region **530** exit via the pumping port **524** into the vacuum pump **540** and, likewise, the gases of the right-hand processing region **580** are evacuated via the same pumping port **524**. Together the two processing region **530**, **580** and the common vacuum pump **540** form a wafer processing system. As far as the plasma is concerned, the plasma on each side of the partition **502** sees only its own processing region as though it were still a separate chamber. In each processing region the plasma is created separately. However, the two processing regions **530**, **580** have common processing conditions since they are connected to the same exhaust pump **540** and, thus, have the same pressure.

55. Services to the two chucks **510**, **560** are <sup>provide</sup> provides via respective stem portions **514**, **574** that extend through the bottom wall of the chamber.

56. Referring to **Fig. 9**, another dual processing region alternate embodiment according to the present invention is illustrated. Twin processing regions **531**, **581** are

disposed adjacent to one another in a single chamber **501** to provide substantially identical processing conditions for a pair of wafers **550, 590**. The two processing regions **531, 581** are separated from one another by a partition **502** that extends down at least below the chucks **511, 561**.

57. Each of the processing regions **531, 581** has a respective chuck **511, 561** on which the respective wafers **550, 590** are supported for processing. The illustration of the wafers **550, 590** and their supporting chucks **511, 561** in phantom indicates a raised position for the chucks that places the wafers **550, 590** in close proximity to the gas distribution shower heads **536, 586**.

58. In a lowered position, the chuck **513** is disposed just below the level of the wafer transfer passage **534** through which the wafer **550** passes into and out of the left-hand processing region **531**. Likewise, the chuck **563** in the adjacent right-hand processing region **581** is disposed just below the level of the wafer transfer passage **588** when in its lowered position.

59. The chuck **513** in the left-hand processing region **531** is supported via a stem **527** having an inner portion **529** that is free to move upwardly thus placing the chuck **511** in its upper position. Likewise the chuck **563** of the right-hand processing region **581** is supported by a stem **577** having an inner portion **579** that is free to move upwardly thus placing the chuck **561** in an upward position. The change of length aspect of the stems **527, 577** is preferably facilitated by respective bellows structures (not shown in this view) that are interior to the illustrated stem portions **527, 529, 577, 579**.

60. According to this embodiment, the stems **527, 577** are substantially aligned with the center of their respective chucks **513, 563**. This centered stem configuration ensures that a proportion of the chucks hang over the pumping port **524** while simplifying the stem-to-chuck interface. Services to the two chucks **513, 563** are provided via respective stem portions **515, 575** that extend through the bottom wall of the chamber.

61. The two processing regions **531, 581** are pumped to vacuum via a common vacuum pump **540** through the pumping port **524**. Together the two processing region **531, 581** and the common vacuum pump **540** form a wafer processing system. As far as the plasma is concerned, the plasma on each side of the partition **502** sees only its own

processing region as though it were still a separate chamber. In each processing region the plasma is created separately. However, the two processing regions **531**, **581** have common processing conditions since they are connected to the same exhaust pump **540** and, thus, have the same pressure.

62. Referring to **Fig. 10**, a partial section detail view of a chamber support structure according to any of the embodiments of the present invention is illustrated. A chuck **610** is supported by a stem **620**. The stem **620** is affixed to the bottom surface **612** of the chuck **610** and has a large flange **625** for affixing the entire assembly to the bottom wall of the vacuum processing chamber (not shown in this view).

63. The structure of the stem **620** is shown in partial section to illustrate an exemplary configuration for the stem. A bellows **622** is employed to provide a vacuum limit that permits changes in length of the stem between the flange **625** and the bottom surface **612** of the chuck **610**. An inner telescope wall **628** is linearly moveable inside an outer telescope wall **626**. The telescoped walls **626**, **628** surround the bellows **622** to shield it from direct exposure to the space below the chuck **610**.

64. An inner shaft **614** of the stem **620** provides services to the chuck **610**. RF energy is supplied to the chuck via an RF connection **632**. Fluid couplings **634**, **636** provide for coolant and helium gas supply to the chuck **610** for the purpose of cooling the wafer.

65. On the upper side of the chuck **610**, an electrostatic chuck **616** is formed for holding the wafer (not shown in this view) securely in place during processing. DC potential for powering the electrostatic chuck **616** is provided via the inner shaft **614** along with the other services.

66. The present invention has been described in terms of preferred embodiments, however, it will be appreciated that various modifications and improvements may be made to the described embodiments without departing from the scope of the invention. The present invention is limited only by the appended claims.